Sagebrush Conversion to Grassland as Affected by Precipitation, Soil, and Cultural Practices[1, 2]

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Highlight

The most successful conversions of sagebrush to crested wheatgrass, in areas of the Western United States that receive an average of 8 to 14 inches of precipitation annually, usually occur where the annual precipitation exceeds 10 inches and on soils having medium moisture-holding capacities. Conversion results were intermediate on coarse soils having low moisture-holding capacities and comparatively poor on fine soils having high moisture-holding capacities. Degree of grass establishment varied directly with the big sagebrush vigor-index. Grass production was lower on gravelly sites converted from black sagebrush than on nearby sites converted from big sagebrush. Cheatgrass hindered the establishment of crested wheatgrass in some places. Conversion results were poor on sites where greasewood or shadscale was mixed with sagebrush. These halophytes had usually re-established on the treated sites.

Several million acres of sagebrush, principally big sagebrush (*Artemisia tridentata*), in the Western United States have been plowed and seeded in attempts to produce more forage, reduce erosion, and control undesirable plants. Successful seedings have thus resulted in a more beneficial use of the limited precipitation in arid and semiarid regions. Large increases in forage on seeded areas in many cases has allowed improvement of nearby ranges by the reduction or deferment of grazing. Several million additional acres of sagebrush probably will be converted to grassland within the next one or two decades.

Other means besides plowing and seeding are sometimes suitable for improving the perennial grass cover of rangelands. Spraying the sagebrush with 2,4-D to release native grasses is often successful. Other practices that may be effective are: (1) reduction or deferment of grazing, (2) changing the class of livestock, or (3) changing the season of use.

Pechanec et al. (1965), Hull and Holmgren (1964), Hull et al. (1962), and Plummer et al. (1955) have all listed climatic, soil and plant-indicator criteria for selecting sagebrush areas suitable for converting to a perennial grass range. Most of these authors also made recommendations on sagebrush elimination methods, seeding methods, species to seed, and grazing management.

This study conducted in cooperation with the U.S. Bureau of Land Management in 1963 and 1964 had two objectives. The main objective was to investigate the effects of annual precipitation, soil properties and cultural practices on crested wheatgrass (*Agropyron desertorum*) establishment in sagebrush regions of the Western United States that receive an average of 8 to 14 inches of precipitation annually. A related objective was to assess several species of sagebrush, occurring alone or mixed with associated shrubs, as indicators of the seeding potential of sites where they occur.

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Study Areas and Methods

Forty-eight study sites were selected on 20 crested wheatgrass seedings in northern New Mexico, western Colorado, Utah, Wyoming, southwestern Idaho, southeastern Oregon,

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and Nevada. Each site was near the border of a seeding and consisted of a treated part and a nearby untreated part.

Information obtained from Bureau of Land Management district records included: methods and dates of sagebrush control and grass seeding, species seeded and seeding rates, grazing history and schedules, precipitation estimates and general weather conditions for the two years after seeding.

Most of the seedings had been plowed twice with a wheatland or brushland disk plow or a heavy offset disk. An excellent kill of sagebrush had resulted in most places. Sixteen seedings had been seeded with either a grain or rangeland drill; three had been seeded with some type of ground-operated broadcasting equipment. Part of one seeding had been drilled and the remainder broadcast. Nearly all of the seedings were at least 2 years old and their ages ranged to 14 years. Most of the seedings were fenced and livestock had been excluded for two years following treatment; the seedings usually had been grazed lightly the third year and in accordance with proper management thereafter.

A distinctive feature of this investigation was the selection of 2 to 6 study sites at each of 11 seedings that had variations both in the shrub associations and in crested wheatgrass establishment. At the other 9 seedings, the shrubs on the untreated areas and grass stands on the seedings were relatively uniform. Only one representative site, therefore, was chosen on those seedings.

Low areas where water collects were avoided. Most sites were flatlying or on slopes of less than 6%, but a few were on slopes ranging from 6–13%. Most of the slopes were exposed to the south, west, or southwest.

A soil pit was dug in each treated and untreated site to the depth of normal wetting as indicated by (1) a marked decrease in root density, (2) a change in structure and hardness or, (3) the presence of bedrock or a caliche layer. The soils were sampled in contiguous increments which correspond to the A, AB, B, BC, and C horizons. The horizon designation, texture, structure, and dry consistence of each sample was noted using criteria and terminology of the U.S. Soil Survey Staff (1951); estimates of the rock content, relative lime content, and root density were made for each sample. The soil parent material(s) was identified at each site.

Line intercept and height measurements were made to describe the shrub species on the untreated sites and on treated sites where shrubs had survived the treatment or had reinvaded.

Five 9.6 ft^2 plots were clipped on each treated site that had some grass present. Crested wheatgrass yields were estimated on three sites where the growth of grass had been delayed by spring drought. Utilization estimates were made for sites that had been grazed, and the yields were adjusted accordingly. Plots were also clipped on untreated sites that had abundant understories of cheatgrass (*Bromus tectorum*) and Sandberg bluegrass (*Poa secunda*).

Moisture content of saturated soil (methods 2 and 27B, Richards, 1954) was used in this study as an index of the moisture-holding capacity (MHC) of the soil. Richards (1954) reports that the moisture content of saturated soil "is directly related to the field moisture range"; one-half the moisture content of saturated soil is suggested as an approximation of the field capacity of the soil. Besides being simple and rapid, the saturation procedure allows expression of the effect of gravel on the MHC. In other MHC procedures, such as the moisture equivalent, the gravel is removed and the measurement is made using only the fines. Gravel fragments occupy space and, depending on their porosity, reduce the moisture storage capacity per unit of depth of soil.

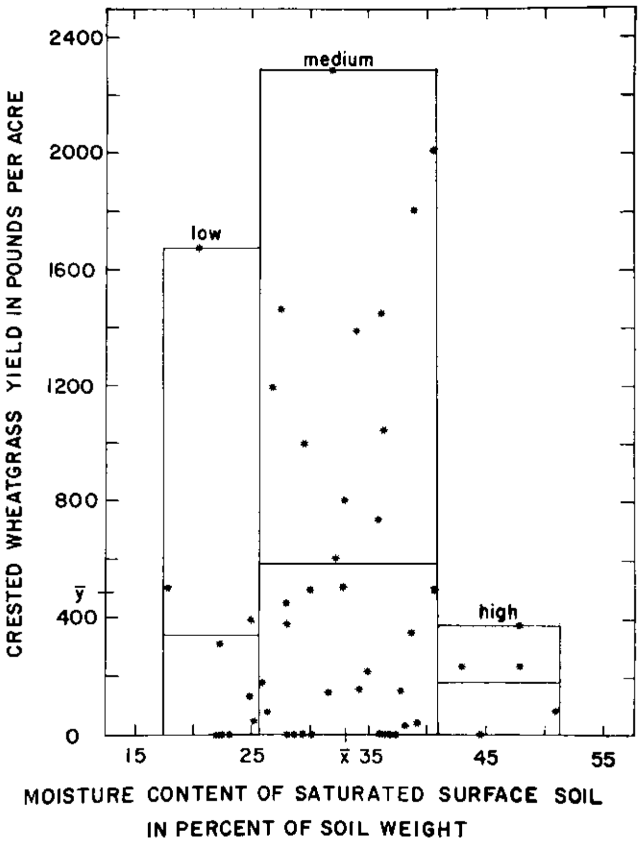

FIG. 1. Relation of moisture contents of saturated surface soils to crested wheatgrass yields of all sites by low, medium, and high moisture-holding capacity groups. The line across each bar marks the grass yield mean for that soil group.

Electrical resistance of each saturated soil sample was determined with a probe cell coupled to a 1,000 cycle, A.C. bridge. The resistance values were converted to electrical conductivity values by means of a standard formula (method 4a, Richards, 1954). The pH of each sample was measured with a glass electrode pH meter to check for excess sodium.

Results and Discussion

Success or failure of attempts to convert sagebrush lands to grasslands appears to be the result of a complex interaction of climate, soil, treatment methods, and grazing management.

Relation of Soil Moisture Characteristics to Grass Establishment

The effect of MHC on crested wheatgrass establishment and subsequent forage production was evaluated by plotting the crested wheatgrass yields against the moisture content of the saturated surface soil (Fig. 1). The value for the surface soil was used because the surface soil is the part of the soil profile most important in affecting germination and early seedling development of grasses, and it is the part of the soil that is wetted most frequently. In general the surface soils were composed of the A and AB horizons and were usually four to eight inches deep.

The data were separated into three MHC groups (Fig. 1) on the basis of the nearly normal frequency distribution having 17% of the samples in the low group, 70% of the samples in the medium group, and 13% in the high group. Mean moisture content at saturation was 33% and the standard deviation was 8%.

Perennial grass production on the untreated areas was usually very low and for practical purposes was considered negligible. Therefore, each crested wheatgrass yield in Fig. 1 represents either an increase or no change in grass production due to the treatment. The three yield ranges overlap considerably because of extreme variability in the yields of the low and medium groups and some poor yields in all groups. The within group variability, in part, is attributed to differences in both average annual precipitation and amounts of precipitation during the periods when the seedings were becoming established. Other sources of variability, which will be discussed later, include differences in: (a) competition from other species, (b) seeding methods, and (c) soil salinity.

Yield of grass at a particular location varies from year to year with precipitation and growing conditions. The precipitation was about average or above average for most sites the year they were sampled, so those yields may be higher than the long-term average. Also, some of the yields may exceed their long-term average because many of the seedings were young, having been planted since 1960. Owing to drought, several of the sites seeded in 1960 and 1961 had rather poor stands of grass. Under proper management these stands may improve during favorable moisture years. A noticeable increase in cover of a crested wheatgrass stand was observed between 1963 and 1965 on a seeding near Ely, Nevada, during which time the annual precipitation was two to four inches above normal.

The data in Fig. 1 show that highest yields occurred on soils with medium moisture-holding properties. These are soils that have an optimum balance among the properties of moisture infiltration, MHC, and moisture availability to plants. The soils of the medium group are sandy loams, loams, or silt loams at the surface, whereas the subsoils, composed of the B and BC horizons, are usually finer textured. The surface soils are usually loose to moderately hard in dry consistence and have vesicular, platy, or subangular blocky structure, and the subsoils exhibit subangular blocky, angular blocky, or crumb structure. Permeability of soils having these properties is usually good to excellent; they normally absorb and hold available to plants much of the water that results from all precipitation events except those of very high intensity. Reynolds and Springfield (1953), after studying the results of attempts to convert sagebrush land to crested wheatgrass in New Mexico and Arizona, concluded that, "An ideal soil for maximum herbage production is one at least two feet deep having a well-developed profile of sandy loam surface two to six inches deep underlain by a clay of blocky structure."

Soils included in the low MHC group are either sandy, extremely gravelly, or cobbly. The permeability of sandy or gravelly soils is normally excellent. However, coarse-textured soils usually do not have enough particle surface area or enough pores of a sufficiently small diameter to retain an adequate quantity of water in the root zone of crested wheatgrass seedlings to sustain them through periods of low precipitation. Nonetheless, many sagebrush land soils which have sandy surface layers also have medium-textured subsoils which retain moisture that infiltrates following snowmelt or large rainstorms. If moisture is relatively abundant during the seedling stage, allowing the establishment of a well-developed root system, then the mature plants can make use of moisture stored in the subsoil. This can account for the fairly productive crested wheatgrass stands sometimes found on soils having sandy surfaces.

Soils in the high MHC group contain more clay than the soils in the medium and low groups. Most of the surface soils are silty clay loams and the subsoils are either clay loams or clays. These soils are angular blocky or massive in structure and normally are very hard when dry. These properties indicate that these soils cannot admit water as rapidly, and runoff is more likely to occur from them than from the soils of the other groups. Because of the high moisture-holding capacities of these soils, much of the moisture is retained near the soil surface where it is quite vulnerable to evaporation. Particle contact is much greater in fine-textured soils than in coarser soils resulting in greater movement of moisture upward during the drying phase in response to moisture tension gradients. This may increase the amount of water lost by evaporation. Also, fine-textured soils have more particle surface area and a given quantity of water is retained in thinner films at higher tensions, thus less moisture is readily available for uptake by plants.

Site Groups

Correlation coefficients were usually very small when the crested wheatgrass yields were compared to any of the measured soil, natural vegetation, or estimated precipitation values for all of the sites. Therefore, sites that had at least one characteristic in common were grouped as shown in Table 1.

Table 1. Characteristics of sagebrush-seeding site groups.

Group	No. of sites	Crested[1/] wheatgrass yield (lb/acre)	Big[2/] sagebrush vigor-index	Estimated annual precipitation (inches)	Moisture content at saturation (percent)		Soil profile mean		Root penetration of herbaceous species (inches)
					Surface	Subsoil	Electrical conductivity (mmhos/cm at 25°C)	pH	
Successful	10	2,290	65	14	41	54	1.52	7.8	31
		1,535	41	12	32	38	.88	7.0	20
		1,010	24	11	20	21	.58	6.2	16
Moderately successful	16	812	72	14	48	50	3.11	7.5	28
		386	37	10	31	32	.88	7.1	19
		132	14	8	17	23	.33	6.7	12
Cheatgrass competition	7	744	53	11	51	66	1.74	7.0	31
		297	40	11	40	51	1.14	6.6	23
		46	20	11	28	31	.68	6.3	16
Halophyte	8	608	37	14	42	46	5.16	8.1	28
		124	26	11	30	32	1.94	7.6	14
		0	16	9	22	24	.59	7.4	12
Failure	7	tr	55	11	44	49	1.06	7.7	20
		0	28	9	32	36	.72	7.3	16
		0	5	8	23	20	.39	6.9	12
Mean for all sites	48	505	35	11	33	36	1.07	7.1	19

1/ The top number in each cluster is the high value, the middle number is the mean, and the bottom number is the low value for the group.

2/ The big sagebrush vigor-index was obtained by multiplying the average height in feet by the percent cover.

The soils and root data shown are for the treated sites; the data were similar for the untreated sites.

Precipitation effects

The data in Table 1 show a general relationship between annual precipitation and crested wheatgrass establishment as reflected by the grass yields. The highest yields occurred in the group which had the largest precipitation mean, 12 inches. The group of sites where no grass was established had the smallest precipitation mean, 9 inches. The average crested wheatgrass yields of the cheatgrass competition group and the halophyte group in Table 1 do not correlate with the average precipitation values for these groups because of competition and salinity factors respectively. These results agree, in general, with the findings of several other workers who have studied the seeding of crested wheatgrass in the sagebrush type. Plummer et al. (1955) reported that rangeland seedings in the Intermountain region could be successful, as a general rule, where average annual precipitation exceeds 10 inches. According to Hull et al. (1962), seedings have not been successful on areas in Colorado having less than 10 inches of annual precipitation. Reynolds and Springfield (1953) found that most of the crested wheatgrass plantings in big sagebrush areas of Arizona and New Mexico receiving less than 12 inches of annual precipitation had been failures.

Favorable distribution of precipitation, moderate temperatures, and permeable soils that readily release moisture to the plants have resulted in the establishment of fair stands of crested wheatgrass in areas where the annual precipitation is only about 8 inches. Five such sites are included in the moderately successful group of Table 1. This corrobates the findings of Plummer et al. (1955), that, "With careful planting in soils having good moisture-holding qualities, successful stands have been attained where annual precipitation is as low as 8 inches." Regardless of the average annual precipitation, it appears that favorable moisture conditions are essential the first one or two years after seeding to establish vigorous plants with well-developed root systems; after establishment crested wheatgrass can survive rather severe drought.

Big sagebrush vigor

The big sagebrush vigor-index (Table 1) was obtained for sites were big sagebrush was the only species or one of the dominant species in mixed types. The general decrease in grass yield means as the big sagebrush vigor-index means decrease supports the widely used criterion that the taller and denser the big sagebrush, the greater the grass production potential of a site. Cheatgrass competition undoubtedly caused suppression of the crested wheatgrass yields of the sites in the cheatgrass competition group and accounts for the lack

FIG. 2. This excellent stand of vigorous crested wheatgrass, 11 years old, replaces the grass-depleted sagebrush range in the background. The forage and soil protection provided makes a beneficial use of the water resource.

FIG. 3. Productivity of this scattered but vigorous stand of crested wheatgrass near Ely, Nevada is limited to about 500 lb/acre because the mean annual precipitation is only about 8 inches.

of correspondence between the vigor-index and grass yield of that group.

Low values of the means of the big sagebrush vigor-indexes and corresponding crested wheatgrass yields for the halophyte and failure groups emphasize the low grass production potential of sites having open stands of short big sagebrush.

Big sagebrush height, density, and vigor, while useful, are not completely reliable indicators of grassland potential. Sagebrush characteristics vary with the age of the shrubs, the subspecies, and with environment. These factors may explain why some sites supported productive stands of crested wheatgrass even though the adjacent sagebrush was not particularly tall, dense, or vigorous. At a few sites the actual grass production appeared to be lower than that indicated by the sagebrush. This was possibly due to the fact that sagebrush has a branching taproot that enables it to extract deep moisture that cannot be reached by crested wheatgrass roots. Also, characteristics of the sagebrush reflect long-time climatic effects, whereas, seeding success is highly dependent on precipitation the first two years after treatment. The grassland potential indicated by the sagebrush, therefore, should be confirmed by evaluating the climate and soils.

Successful group

The successful group is composed of the 10 highest yielding crested wheatgrass sites which were located on 8 seedings in 5 States. An excellent stand of grass, similar to that shown in Fig. 2, existed on all of the sites. The pretreatment vegetation on nine of the sites was vigorous big sagebrush and was mixed big sagebrush and black sagebrush (*Artemisia nova*) on the tenth site. The low and mean values of the sagebrush vigor-indexes are the largest ones of the five groups in Table 1. The annual precipitation mean is the largest of all groups, and it is noteworthy that all of the values for this group exceed 11 inches. All except one of these sites had soils in the medium MHC group (Fig. 1).

Moderately successful group

The moderately successful group consists of sites where the crested wheatgrass stands were less dense (Fig. 3) or less vigorous than the stands of the successful group. One of several sagebrush species existed on the untreated sites of this group. Twelve sites were big sagebrush, three sites were black sagebrush, and one site was Wyoming sagebrush (*Artemisia tripartita* subsp. *rupicola*). The principal reason for the intermediate grass yields, evidently, was that there was normally insufficient soil moisture available for abundant grass production.

Various factors seem to be responsible for lower than optimum moisture conditions. Estimated annual precipitation is less than 10 inches for 7 of these sites, including the Wyoming sagebrush site and one black sagebrush site. The low precipitation results in grass stands that are sparse or, on some seedings, fairly dense stands that do not grow vigorously because of intense competition for moisture.

Five sites are in areas having 10 to 12 inches of precipitation, but because of unfavorable distribution of the precipitation and extreme soil conditions, there is probably not enough soil moisture for abundant grass production. Three of the sites have relatively fine-textured soils; when saturated, the moisture contents of their root zones average 38 to 40%. One site has a very fine-textured soil; its moisture content at saturation is about 50%.

The crested wheatgrass yields for these four sites averaged about 360 lb/acre in 1964; production is probably limited to about that level by the adverse moisture-absorbing and moisture-holding properties of the fine-textured soils. The soil at another site is sandy; when saturated, the average moisture content of its root zone is 26%. The low grass production of that site, 132 lb/acre in 1964, is apparently due to the low MHC of the soil and to the lack of sufficient precipitation.

The black sagebrush sites are on gravelly terrace and fan deposits. Small gravel forms a pavement on the surface and occurs in the surface soil. In general, the gravel increases in size and quantity with depth; at 12 to 16 inches gravel constitutes at least 50% of the lower root-zone and the rock content is even greater below that. The MHC of the surface soils averaged 31.6% and the MHC of the subsoils averaged 25.4%. Grass root penetration averaged 14.5 inches for these sites as compared to an average of 18 inches for all of the sites converted from big sagebrush. Miller and Bunger (1963) and earlier workers have shown that a coarse sand or gravel layer underlying a uniform soil impedes water movement, because of a reduction in particle contact and surface area, and causes more moisture to be retained in the soil above the coarse layer. This may be a disadvantage because water held in the surface soil is quite vulnerable to evaporation, and may explain why the black sagebrush sites appear to be drier than nearby big sagebrush sites.

Crested wheatgrass production averaged 500 lb/acre on the three sites converted from black sage and 1,550 lb/acre on three other sites on the same seedings converted from vigorous big sagebrush. These results are not in agreement with the report of Plummer et al. (1955) that adjacent big sagebrush and black sagebrush ranges in Nevada and central Utah yielded similar amounts of crested wheatgrass.

On two sites of this group, competition from big sagebrush appeared to be severe enough to prevent high grass production. One of these sites had been plowed and seeded 8 years prior to investigation. The aerial cover of the reinvaded sagebrush amounted to 40% of the cover on the adjacent untreated site. Other undesirable features of this site were a root zone that contained about 35% gravel by volume and a basalt bedrock at 12 inches, resulting in a low MHC. At the other site, which had been treated about one year before examination, the cover of big sagebrush was about 30% of that on the untreated. Although the grass stand probably was not completely established, its growth and production was undoubtedly being hindered by the sagebrush competition.

Cheatgrass competition group

The cheatgrass competition group is composed of seven sites where generally poor stands of crested wheatgrass were mixed with cheatgrass and usually Sandberg bluegrass. In 1963, the cheatgrass production ranged from 184 to 988 lb/acre on these sites and the mean was 648 lb while the crested wheatgrass mean was 297 lb. Sandberg bluegrass yield varied from 0 to 594 lb/acre having a mean of 292 lb. The amount of cheatgrass present during the seedling stage of the crested wheatgrass was not kown, but apparently competition was great enough to prevent the establishment of full stands of crested wheatgrass on all of the sites.

Five sites in this group were on the same seeding and were within a few hundred yards of each other. Low sagebrush (*Artemisia arbuscula*) was the only shrub species on two of the adjacent untreated sites and was mixed with antelope bitterbrush (*Purshia tridentata*) on a third site. The other two sites had quite vigorous big sagebrush next to them. Moisture contents of the saturated soils indicated that the soils were finer textured than optimum for establishing created wheatgrass (Table 1), but the abundance of cheatgrass and Sandberg bluegrass, both on the seeding and as understory on the untreated sites, is indicative of a high grass production potential.

The remaining two sites of this group were located on two other seedings. Big sagebrush at one of the sites was moderately vigorous and a fairly dense understory of cheatgrass was present the year of sampling. Natural vegetation at the other site was a mixture of big sagebrush, rubber rabbitbrush (*Chrysothamnus nauseosus*), and spiny hopsage (*Grayia spinosa*) and a moderately dense understory of cheatgrass. At other sites on these same two seedings, where there was no cheatgrass competition, crested wheatgrass production was approximately 3-fold greater than on the above-mentioned sites.

Particularly in southern Idaho and in some regions of adjoining states, extensive stands of cheatgrass are managed for forage and erosion control, as pointed out by Klemmedson and Smith (1964) in their very comprehensive review of the literature on cheatgrass. In those regions it may be uneconomical to convert extensive areas to perennial grasslands regardless of the fluctuations in production and the fire hazard of cheatgrass. However, if a decision is made to plow and seed any cheatgrass-infested area, there are several methods that can be employed to greatly reduce the cheatgrass (Plummer et al., 1955; Eckert and Evans, 1967) so that a full cover of perennial grass can be obtained as soon as possible.

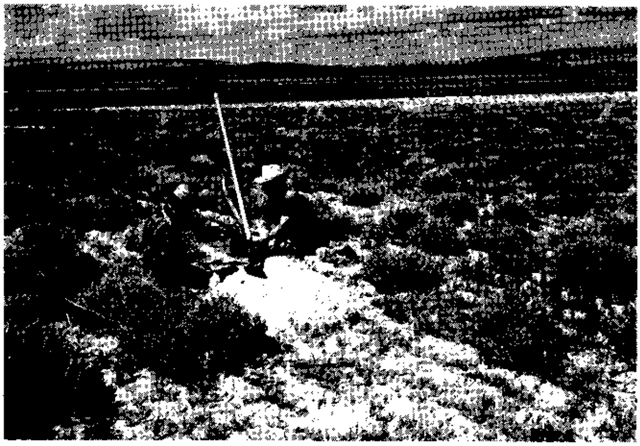

FIG. 4. Vigorous shadscale and Russian thistle on a treated site in northwestern Nevada. Mixed shadscale, big sagebrush, and bud sagebrush (*Artemisia spinescens*) occupy an adjacent untreated area.

Halophyte group

The halophyte group is composed of sites where halophytic shrubs were mixed with sagebrush prior to treatment (Fig. 4). Usually plowing completely eliminated the sagebrush, but the halophytes, shadscale (*Atriplex confertifolia*) and greasewood (*Sarcobatus vermiculatus*), usually have re-established in appreciable amounts as shown in Table 2 and Fig. 4.

Five of the sites had no crested wheatgrass, but they usually had some annual herb, such as cheatgrass, Russian thistle, or an annual mustard in addition to the re-establishing halophytic shrub. The low average grass yield of 124 lb/acre points out the general failure of converting shadscale and greasewood infested sagebrush lands.

Two shadscale sites, sites 18 (Fig. 4) and 24 in Table 2, had hardpans below 10–12 inches. The hardpans probably restrict movement of water; root development in them is poor.

The profile mean pH and electrical conductivity (E.C.) values of the soil pastes of the halophyte group are the highest values shown in Table 1. The mean E.C. of the halophyte group surface soils (9.86 millimhos/cm) is only slightly higher than the mean for the successful group surface soils (9.71). The halophyte group subsoils are considerably more saline than the successful group subsoils having mean E.C.'s of 2.38 and 0.95 respectively. The computed average osmotic pressure of the surface soils at the lower limit of available moisture is about four atmospheres. This osmotic pressure is not very great, but when this negative pressure or tension is added to the physically-induced tension, the total soil moisture tension is undoubtedly great enough to reduce grass seedling survival. Haas et al. (1962) showed crested wheatgrass yields two-thirds that of the nonsaline con-

Table 2. Comparison of the vegetation on treated and adjacent untreated Halophyte Group sites.

Site No.	Shrub cover in percent				Years after treatment	Crested wheatgrass yield (lb/acre)	Saturated paste electrical conductivity (mmhos/cm at 25°C)	
	Shadscale	Greasewood	Big sagebrush	Other			Surface soil	Subsoil
6U[1]	*[2]		21.9				.74	.88
6T	16.0		1.0		8	184	.59	.71
18U	17.0		1.7	.9 Arsp[3]			.63	2.19
18T	12.1				4	0	.71	6.64
19U		10.6	6.4	.7 Grsp[4]			1.29	4.33
19T		18.2			4	0	2.17	5.42
24U	8.5		1.7	.4Arsp			.55	.86
24T					3	0	.55	.89
25U	2.3		14.0				.47	.98
25T	.5				3	0	.47	.77
36U			2.1	7.9 Atnu[5]			.67	1.36
36T					3	200	1.03	1.34
41U	5.7	3.1	13.2	.1 Tesp[6]			.78	1.50
41T	3.3				8	0	.66	1.75
42U	1.0	5.9	14.6				.57	.68
42T	.6	3.1			8	608	.73	1.59

1/ U, Untreated; T, Treated
2/ Few scattered plants, none intercepted in the transect.
3/ Bud sagebrush (Artemisia spinescens).
4/ Spiny hopsage (Grayia spinosa).
5/ Nuttall saltbush (Atriplex nuttallii).
6/ Cottonthorn (Tetradymia spinosa).

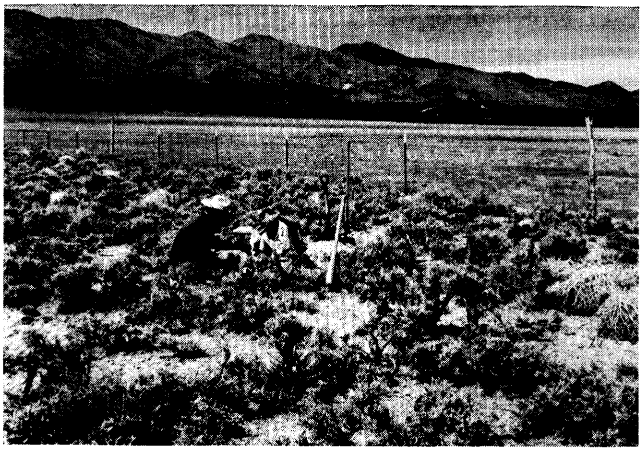

FIG. 5. Only a trace of crested wheatgrass resulted from the plowing and seeding of this site near Ely, Nevada. The big sagebrush lacks vigor, and the subsoil is gravelly.

trol on plots in Idaho made saline to a level similar to the mean salinity of the halophyte group soils.

This study shows that it is difficult to convert to grasslands where the vegetation includes greasewood or shadscale. Hull (1963) conducted seeding trials at several locations in Wyoming where Nuttall saltbush occurred alone or mixed with other shrubs including big sagebrush and shadscale. After 11 to 14 years, crested wheatgrass and Russian Wildrye (*Elymus junceus*) stands had deteriorated until they were poor or gone. If treatment of halophyte lands is necessary, arcadia-type contour furrowing and seeding as discussed by Branson et al. (1966) may be effective.

Failure group

The failure group consists of eight big sagebrush sites where crested wheatgrass failed to become established (Fig. 5). The vigor-index of big sagebrush for this group was next to the lowest of all groups. The structure of the subsoils and the penetration of the roots of the annuals on these sites indicate that there is less soil moisture available for plant growth than on most of the other sites in the study.

The relatively low mean value for the estimated annual precipitation partially explains the deficiency of soil moisture on these sites. At most of these sites, the soils are deep enough and have the proper chemical and physical characteristics to support vigorous, productive stands of grass if precipitation and the resultant soil moisture were less limited.

Four of the sites are on seedings where the annual precipitation is about 8 to 9 inches. The soils on two of these sites, one of which is shown in Fig. 5, have low moisture holding capacities; possibly there was insufficient moisture held in the surface soil at the right time to promote grass establishment. On another site, the surface soil has a moisture content at saturation of 35.4%. Considering the very limited moisture conditions, the soil may be of fine enough texture to prevent the survival of grass seedlings. A silty crust about two inches thick existed at the soil surface and this may hamper infiltration of water. One site is located on an alluvial fan that had a dense cover of annual mustard, both on the treated area and as an understory species on the untreated area. If the mustard was there during the seedling stage of the grass, the competition for moisture was probably detrimental to the grass. A good stand of grass exists on the part of the seeding not on the mustard-covered fan.

The soils at two other sites were medium-textured but had quite high moisture contents at saturation. In consideration of these soil properties, annual precipitation of 11 inches probably does not result in enough available soil-moisture for strong plant growth. However, one of these sites is located on a stock driveway and grazing during the seedling stage may have contributed to the failure.

Type of seeding equipment may have contributed to the poor results of the sites in this group and a few sites in other groups. Two sites that had been broadcast seeded were failures. On the same seeding, two other sites that had been drilled were moderately successful. Information was not always available as to the type of furrow-openers used on the drills, however, it appeared that deep-furrow openers had not been used on the seedings in this group. A study by McGinnies (1959) confirmed that where moisture is limited the best stands of grass were obtained by using drills equipped with deep-furrow openers. Several writers have, nonetheless, cautioned that deep-furrow openers should not be used where soils are likely to slough or blow, thus covering the seed too deep.

Loose seedbeds, which allowed the seed to be planted either or both too deep or in poorer contact with the soil, were sometimes mentioned by Bureau of Land Management personnel as a probable cause of failure at some of the sites. Hull et al. (1962), and Plummer et al. (1955), emphasized that on loose or rough seedbeds, drills should be equipped with depth bands and packer wheels.

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